Neutrino Factory Acceleration Scenarios

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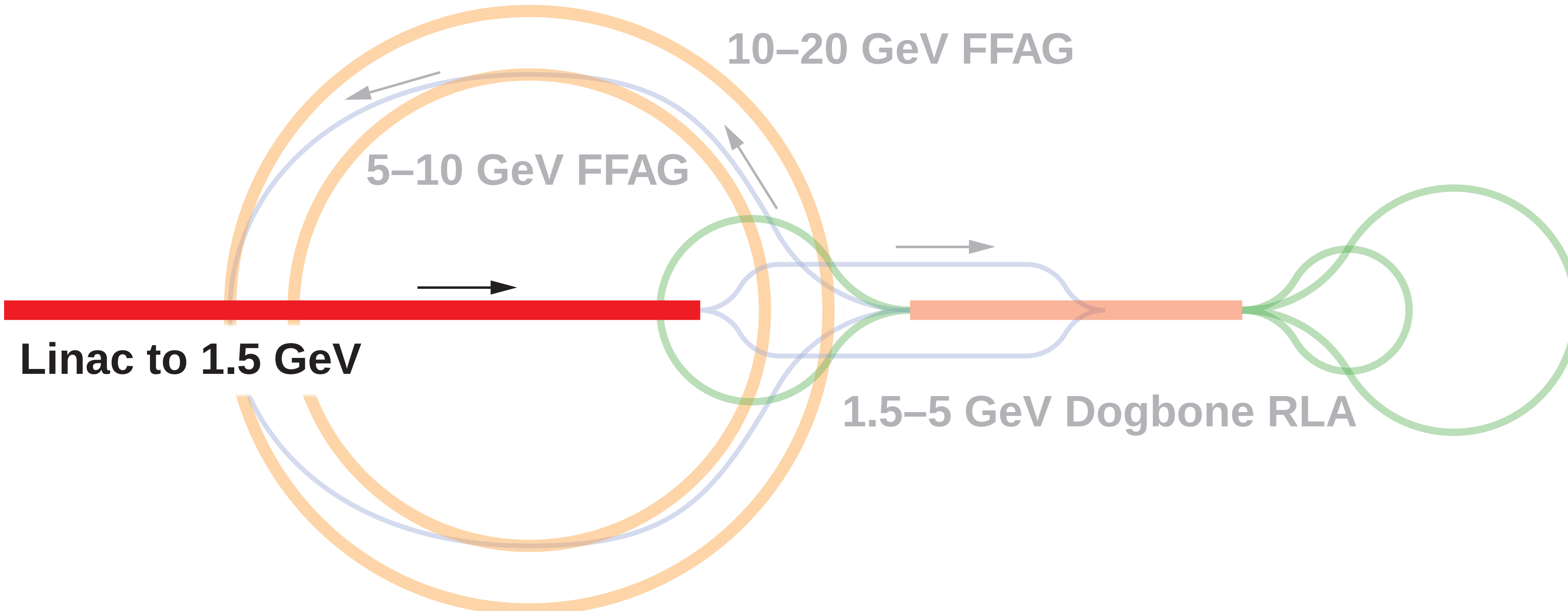
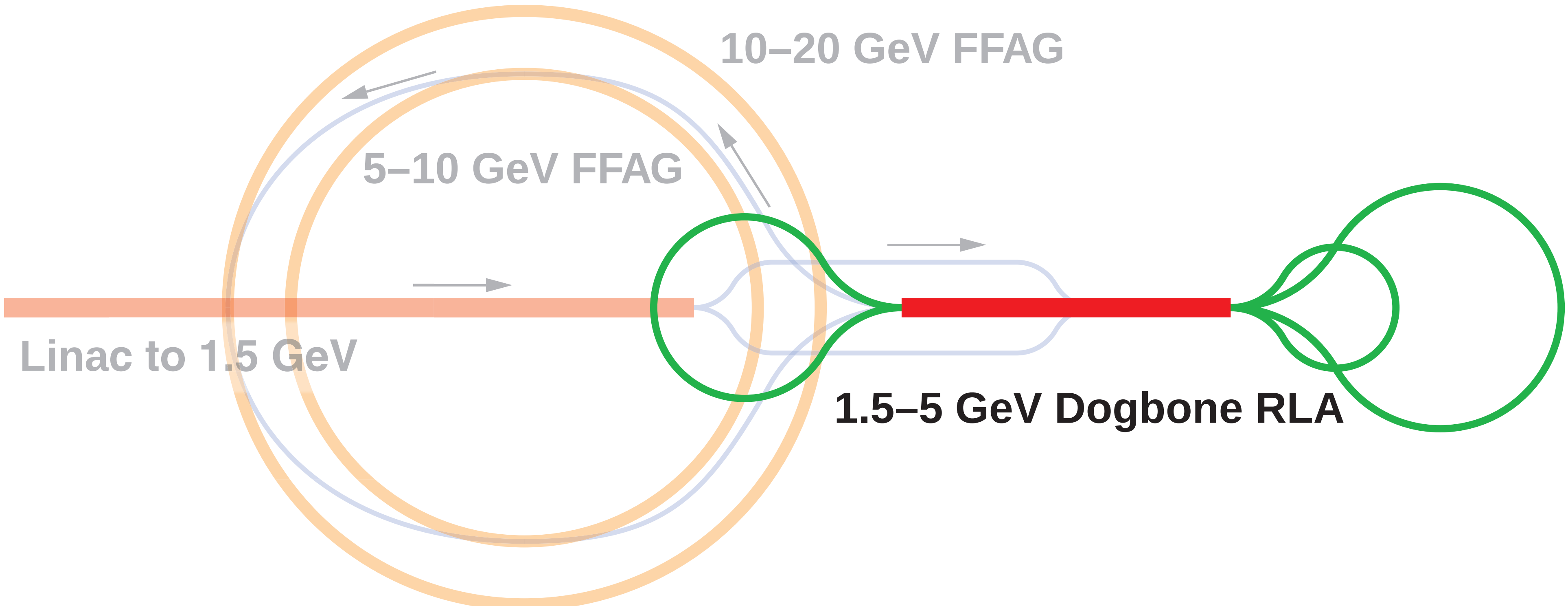
Outline

- Recent work on the RLA
- Tracking in linear non-scaling FFAGs
- Electron model for linear non-scaling FFAG (EMMA)
- Analysis of an isochronous FFAG
- Analysis of a scaling FFAG scheme

The Study IIa Scheme
Linac



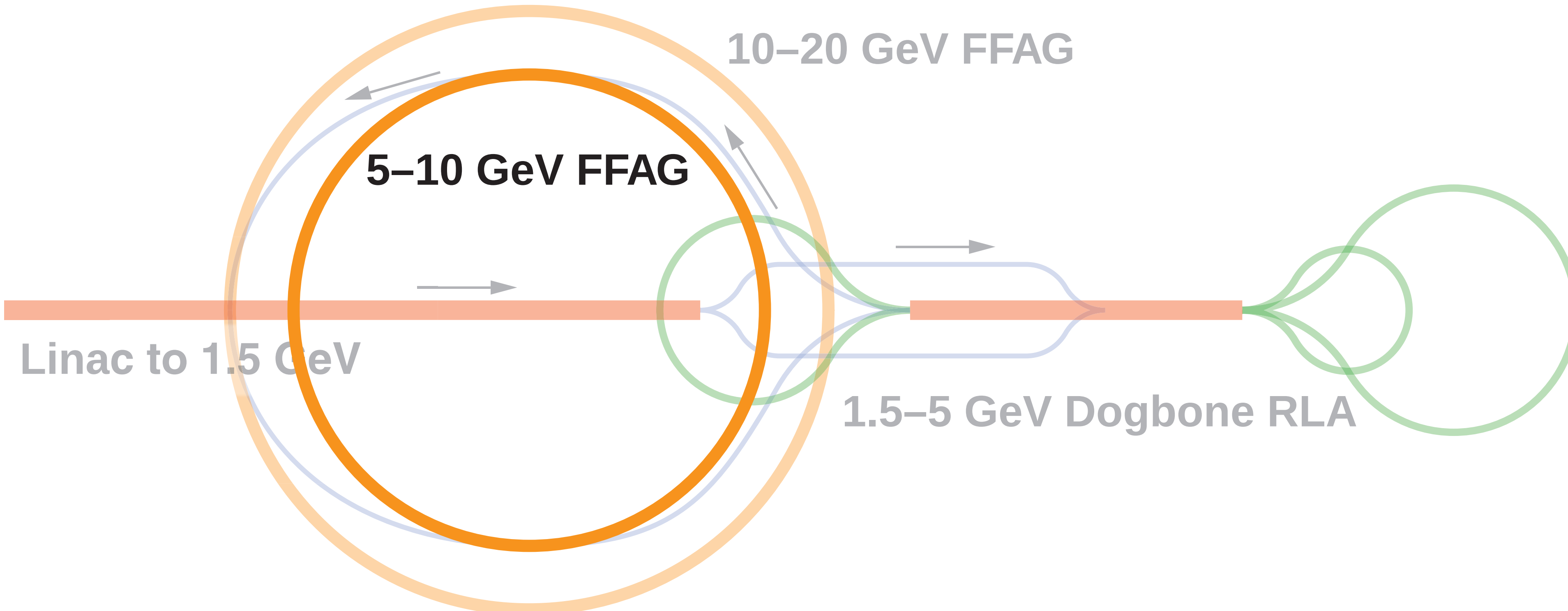
The Study IIa Scheme
Dogbone RLA



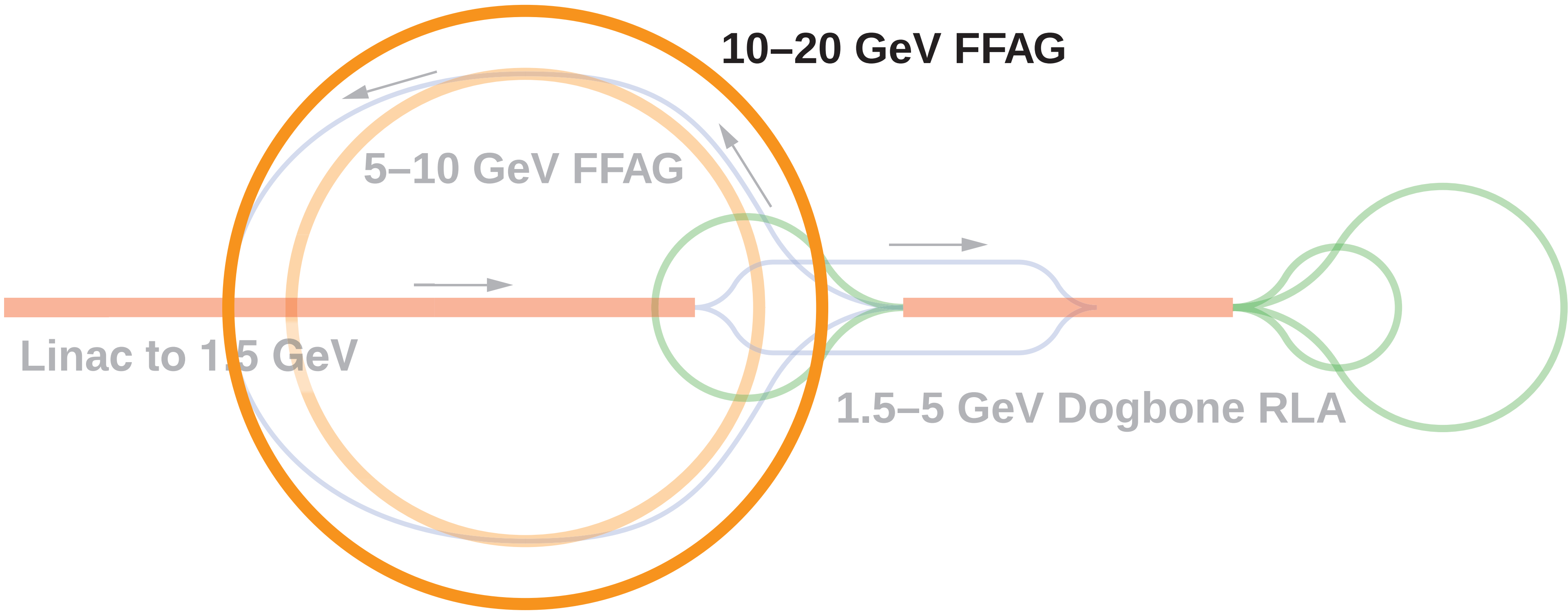
Dogbone RLA

- Full linear design exists
  - Needs to be converted into real terms, costed
  - Compare cost per GeV to FFAGs
- Misalignment and gradient error sensitivity studied
  - Orbit distortion manageable with 1 mm magnet displacements
  - Quad field tolerances 0.2%
- Next steps
  - Add sextupoles to get chromatics right
  - Look at beam with finite energy spread

The Study IIa Scheme
5–10 GeV FFAG



The Study IIa Scheme
10–20 GeV FFAG



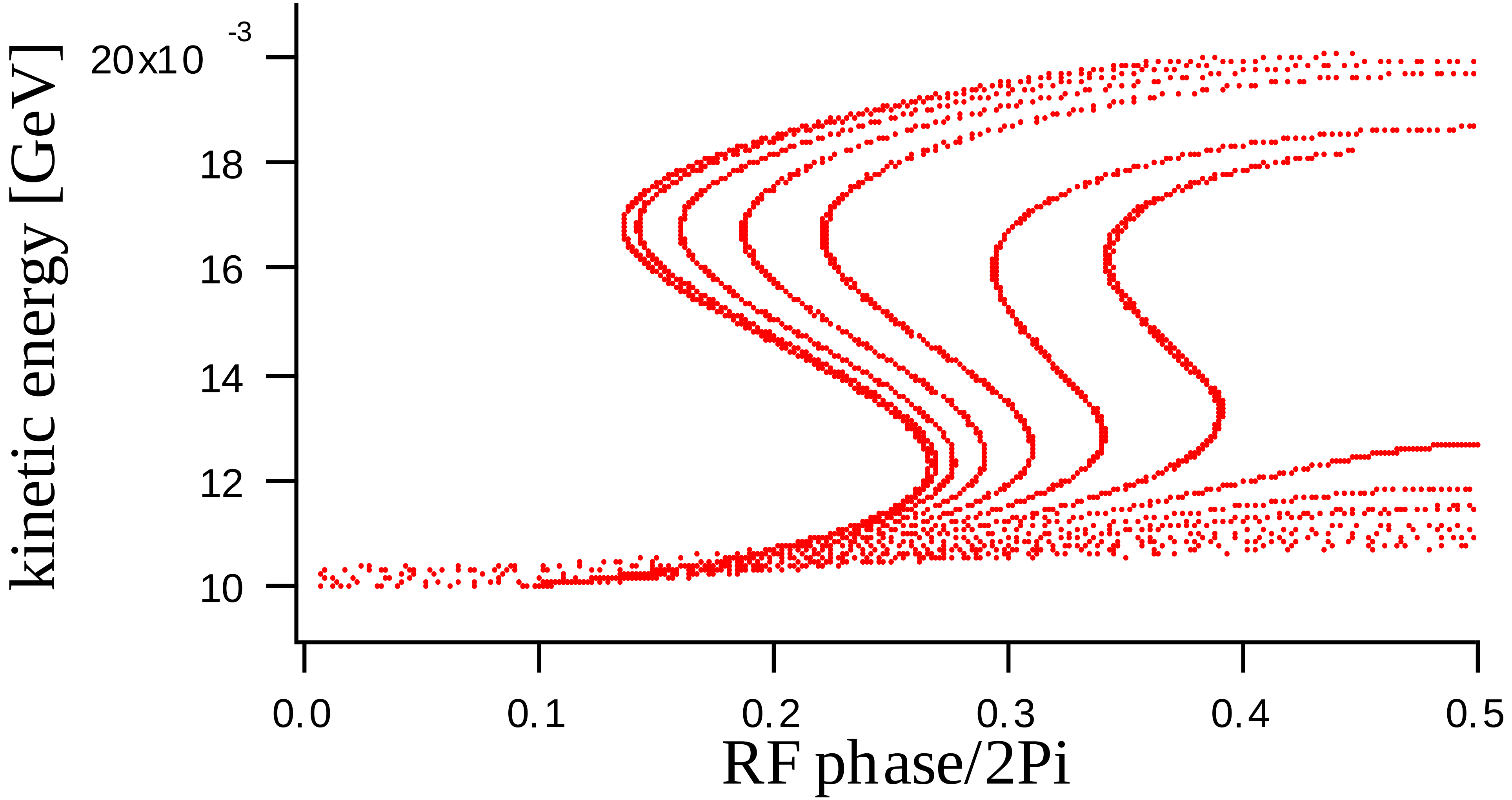
Tracking in Linear Non-Scaling FFAGs

- 6-D tracking studies have begun on linear non-scaling FFAGs. Most codes can't handle FFAGs well.
  - Most of this done by European collaborators (Machida, Méot, Lemuet)
- With real acceleration, particles with high transverse amplitude aren't accelerated properly
  - Not a problem with uniform acceleration (what we tested before)
  - Low transverse amplitudes are fine
- Cause: time of flight depends on amplitude
  - Can predict the dependence:

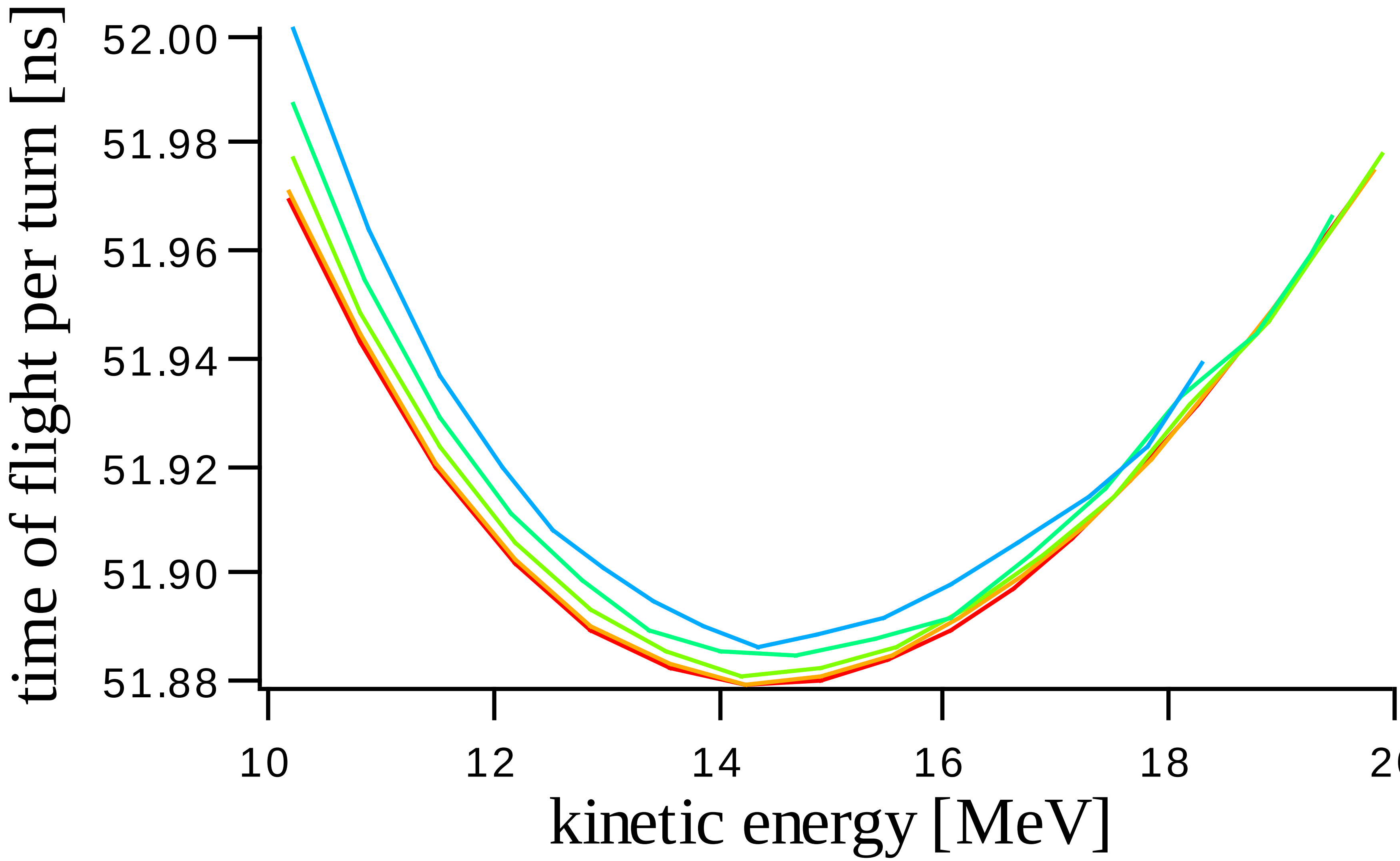
$$\frac{dT}{d\boldsymbol{J}} = -2\pi p \frac{d\boldsymbol{\nu}}{dE}$$

  - No effect in scaling FFAGs!

Time of Flight Dependence on Amplitude
Different Transverse Amplitudes



Time of Flight Dependence on Amplitude
Time of Flight Curves



Tracking in Linear Non-Scaling FFAGs
Time of Flight Dependence on Amplitude

- How will we address the problem?
  - Adjust machine parameters to open up the channel more
    - More voltage
    - Longer ring
    - Higher harmonic RF
    - Costs money
  - Adjust phase space more carefully to optimize what we have
    - Current model assumes that time of flight is perfectly parabolic
    - Find best area of overlap (right now, using optimum for low amplitude)

FFAG Electron Model

- Linear non-scaling FFAGs have never been built
- Create an inexpensive model of a linear-nonscaling FFAG
- In the last year we have
  - Refined the experimental goals of the machine
  - Settled on lattice specifications
  - Begun to look at hardware

FFAG Electron Model
Basic Experimental Goals

- Study the unique longitudinal dynamics in fixed-frequency linear nonscaling FFAGs
- Study rapid crossing of many weak resonances that occurs in linear nonscaling FFAGs
- Study the effect of errors on the performance of linear nonscaling FFAGs
- Vary machine parameters over a significant range to study these effects as a function of machine parameters
    - RF frequency (part in 10^3)
    - Magnet gradient ($\pm 25\%$) and dipole field ($\pm 50\%$)
    - Magnet displacement and gradient errors
- Compare results to simulation

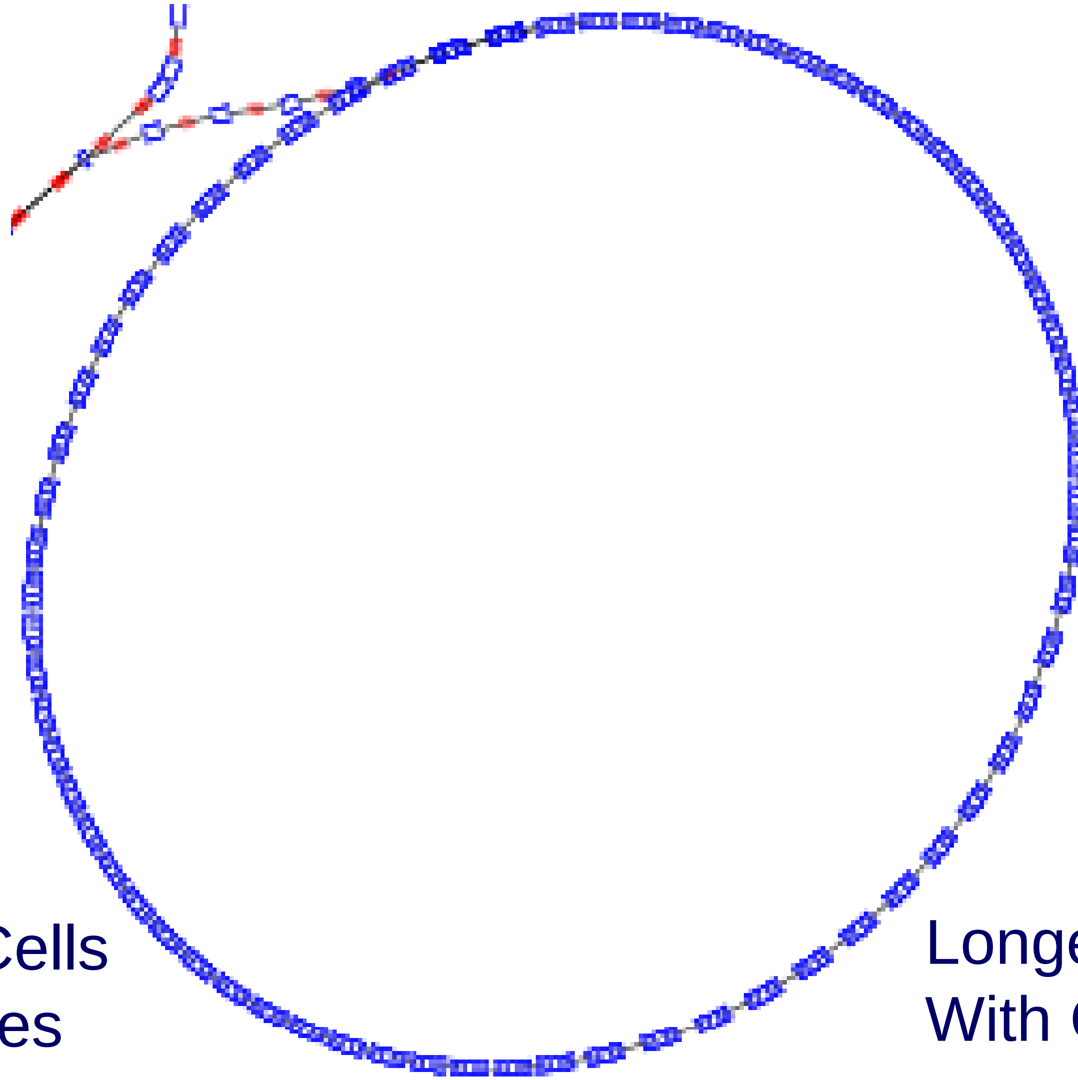
FFAG Electron Model
Lattice Specification

- We have a well-defined baseline lattice
- 42 cell lattice, approximately 16 m circumference
- Accelerating in 14 turns or less
- Magnets with approximately 0.2 T pole tip fields
  - Gradient dipole
  - Shifted quadrupoles

Acceleration Schemes
Isochronous FFAGs (Rees)

- Replace the FFAGs in the NFMCC scheme with "isochronous FFAGs"
- Linear non-scaling FFAGs have a time of flight that depends on energy
  - Difficult to keep bunch synchronized with the RF
  - Puts a lower limit on the required voltage
  - Leads to above described problems
- Use nonlinear magnets to make the FFAG isochronous over the entire energy range
  - Original idea from Rees (RAL)
- Can also use two types of cells: longer cells with RF, shorter cells without (UK baseline)
  - Can reduce machine cost
  - Need to match between: challenge

Isochronous FFAGs with Insertions



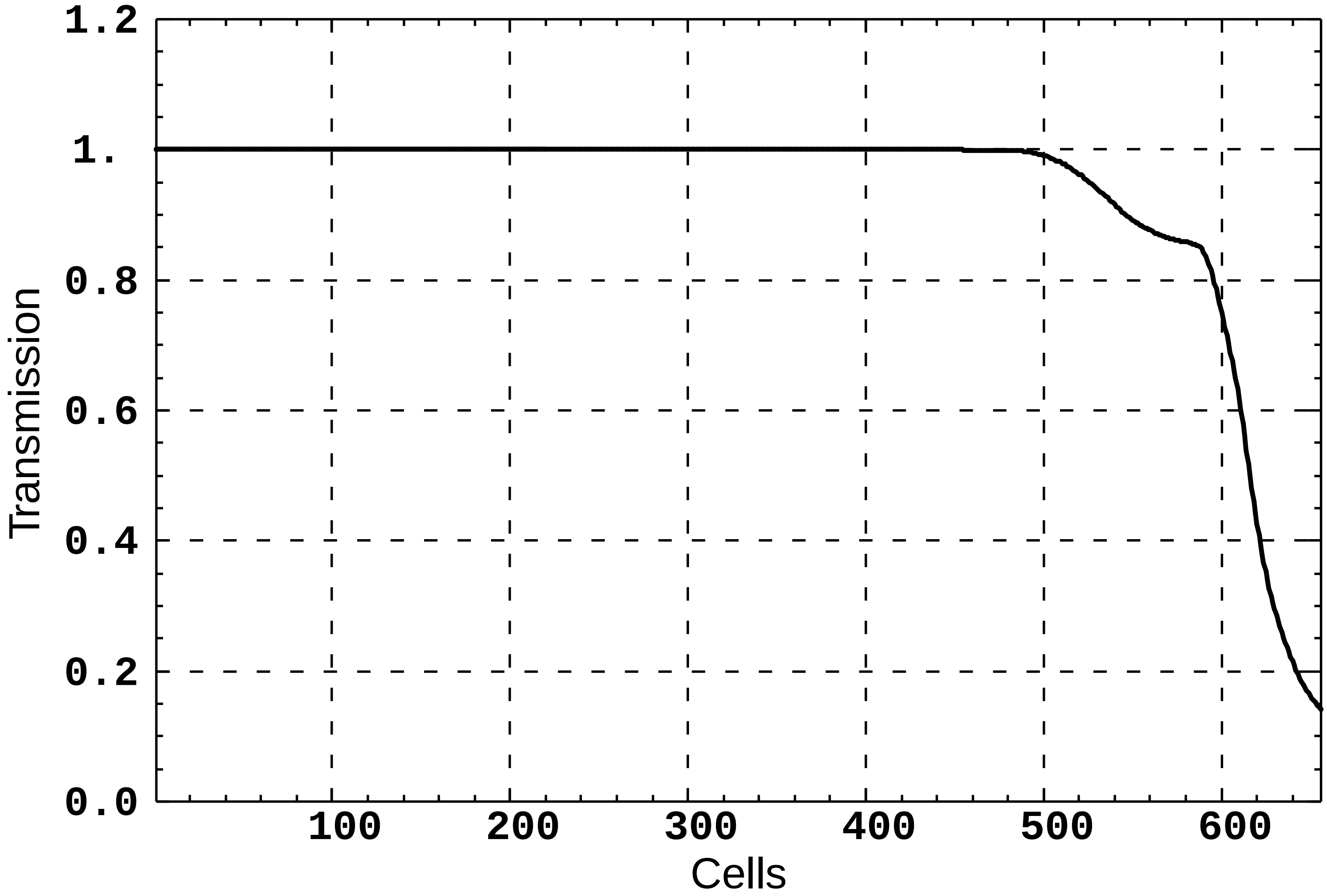
Shorter Cells
No Cavities

Longer Cells
With Cavities

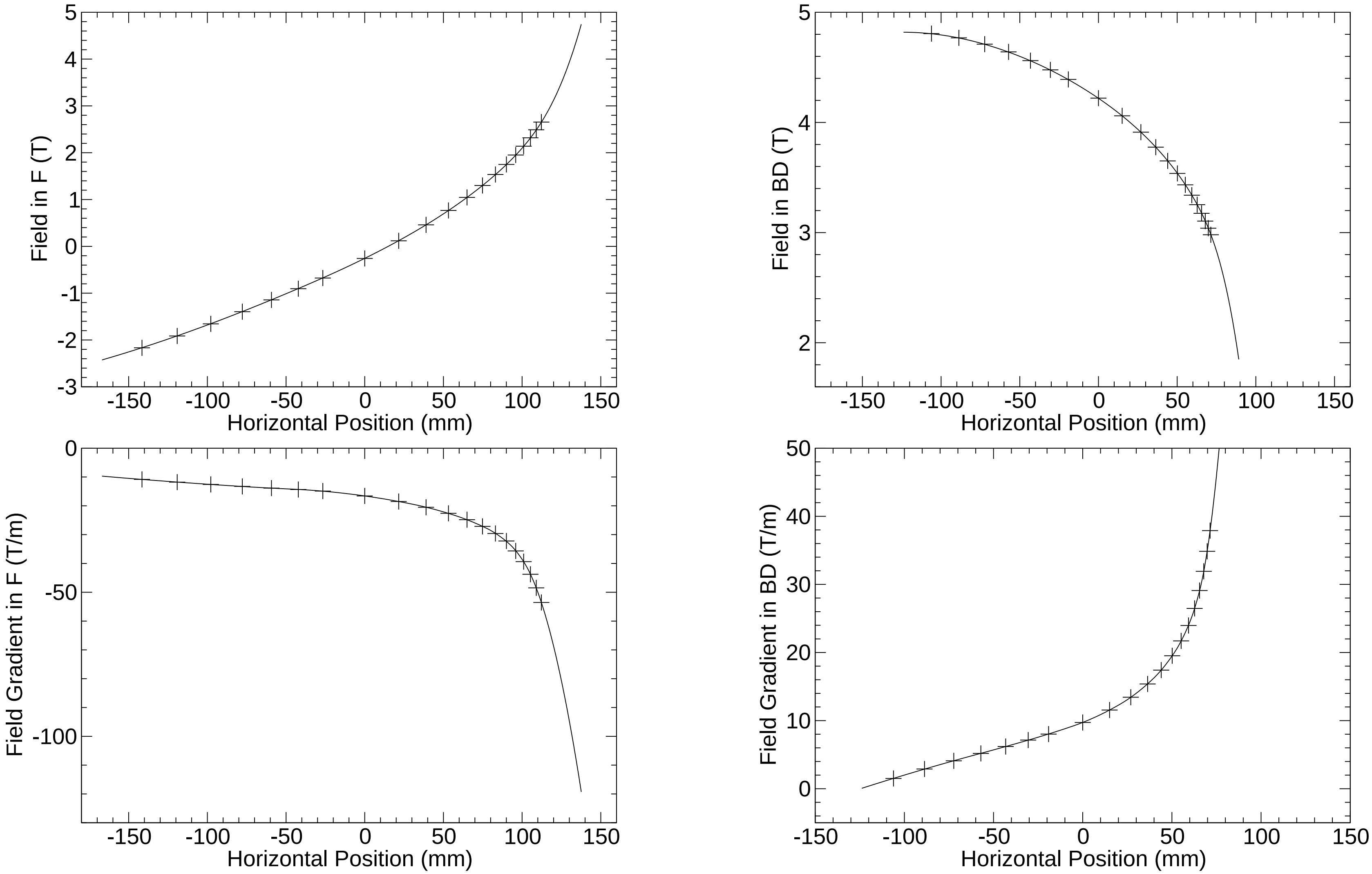
Isochronous FFAG: Analysis

- Time of flight variation is exceptionally small
  - Factor of 10 below natural value
- In my computation, vertical tunes go unstable at high energy
  - Possible cause: Rees uses second-order edge effect which I don't
- Tracking results (Méot/Lemuet)
  - Beam loss at high energy end
  - Appears to come from hitting a resonance
    - Note it occurs about where I say the lattice goes unstable
  - Highly nonlinear fields at high energy could also be driving it into the resonance
- Not performing acceptably at this point
  - Work has not been put into improving it as yet

Isochronous FFAG
Beam Loss



Isochronous FFAGs
Fields



Neutrino Factory Muon Collider

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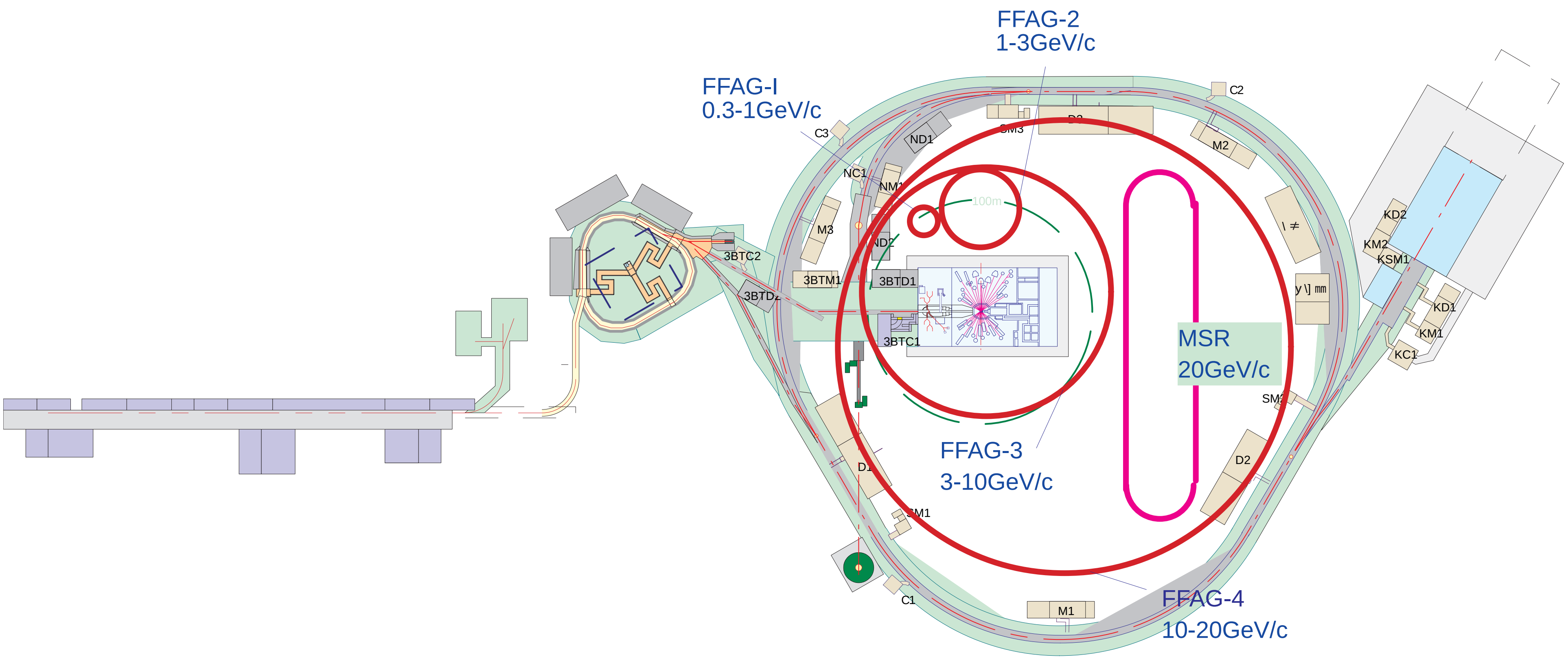
Acceleration Schemes
Scaling FFAGs

- The NuFactJ scheme (KEK, Japan)
- Scaling FFAGs only for entire neutrino factory, from capture to (not including) storage ring
- 4 stages, 0.3–1 GeV/c, 1–3 GeV/c, 3–10 GeV/c, 10–20 GeV/c
- Idea: this may be inexpensive
  - Avoids the entire front end
- Scaling FFAGs can have large dynamic aperture
  - Arbitrarily large energy acceptance
  - No resonance crossing issues
  - Will it be large enough? Nonlinearities.
- Use low-frequency RF to accelerate
  - Lots of voltage needed at low frequency

Scaling FFAGs
FFAGs on Tokai Campus



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Scaling FFAG Scenario

- Lattices presented in the NuFactJ report were to give the idea
  - I attempted to replicate the NuFactJ lattices
  - Lattices were not even stable
  - They were constructed out of standard sector magnets, not FFAG magnets
- I produced a set of lattices
  - Used true FFAG magnets
  - Matched the tunes in the NuFactJ report
- Result had large costs
  - 10–20 GeV was 83% of the entire Study IIa cost, compared with 5% for linear non-scaling FFAG
  - Reason: large apertures (35–45 cm), high fields (up to 9.4 T)
  - Lower energy lattices should have come out normal conducting (didn't)

My Versions of NuFactJ Lattices Magnet Parameters and Cost

- Further optimization improved 10–20 GeV lattice
  - 2002 lattices from LBNL FFAG Workshop: 18% of the entire Study IIa cost, lower due to smaller apertures and fields
- Note: no cavities in cost!
  - RF systems used
    - 0.75 MV/m average over ring, air gap, 5–10 MHz
    - First ring may be variable frequency
      - New type of magnetic alloy core
    - All this needs more careful specification, R&D, costing

Conclusions

- We have an RLA lattice up to 5 GeV, and analysis is proceeding.
- We are trying to compare different FFAG systems
  - Linear non-scaling FFAGs are having problems with large amplitude particles. Know how to address, additional costs.
  - Isochronous FFAGs have serious dynamic aperture problems, but more work may address this.
  - Scaling FFAGs look costly, but optimization seems to be helping that. RF may be an issue.
- We have and are continuing to develop a good experimental plan and design for a model to study linear non-scaling FFAGs
- We have significant international collaboration in this effort